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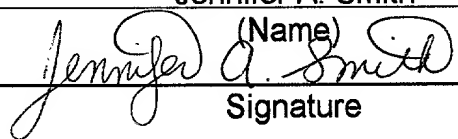
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PRIORITY-DRIVEN DITHER

Field of the Invention

The present invention is directed to the field of digital printing and imaging. It is more specifically directed to the reproduction of digitized documents.

Background of the Invention

Digital documents, containing a mixture of text and pictures are proliferating. Similarly, the number of digital output devices such as digital printers are increasing. A vast majority of digital printers can print only in a bilevel mode, either ink is printed or no ink is printed. The task of converting digital documents into digital output on bilevel output devices involves a process known as halftoning. In halftoning the original continuous tone input is converted to a bilevel image. Digital halftoning is used for printing a picture (or more generally displaying a picture on some two-dimensional medium). It uses small dots with a limited number of colors such that it appears to consist of many colors when viewed at a proper distance. For example, a picture printed with black and white dots may appear to contain various shades of gray when viewed at some distance.

Commonly used methods for digital halftoning include *dithering algorithms* which use *threshold arrays* (also called *dither*

1     *matrices*) or *dither masks*. A fundamental problem in halftoning  
2     is that text is generally not rendered well. Processing  
3     pictures as text or text as pictures results in poor print  
4     output quality. An example of this poor quality would be text  
5     areas erroneously printed as halftones. This results in the  
6     text looking blurred rather than sharp. It is desirable to  
7     have an algorithm that can print both picture and text areas  
8     well.

9     A possible solution is to segment the text and picture areas  
10    and process them separately. The composite document containing  
11    text and pictures is segmented into text and picture areas.  
12    Only the picture areas are halftoned. This technique is time  
13    consuming and error-prone in so much that the segmentation is  
14    rarely performed with total accuracy. Furthermore, when there  
15    are text areas within pictures the segmentation is not well  
16    defined.

17    Goertzel and Thompson (US Patent 4,654,721) present a technique  
18    for edge enhancement in halftones which assigns a number of  
19    pixels to print in an area and orders the pixel values in a  
20    larger area to determine where the printed pels should be  
21    placed. The Goertzel-Thompson invention is based on lower  
22    resolution input data and is not capable of reproducing the  
23    level of image detail required by many applications.

#### 24    Summary of the Invention

25    Thus an aspect of the present invention is to provide methods  
26    and apparatus that can properly print both picture and text  
27    areas using a halftoning technique based on an area-of-support.

Dynamic adjustments are made depending on whether the document area contains text or pictures such that there is a smooth (visually pleasing) transition between text and picture areas.

Another aspect of the present invention is to provide a block-dither method, which involves a limited dependence on the local surround of a pixel.

Another aspect of the present invention is to provide a method which examines a digitized document, decides for each local area how much gray the printer needs to put down, and determines how these pixels are distributed spatially.

Another aspect of the present invention is to provide a method which gradually switches from text rendering to picture rendering in a manner that is locally adaptive over small regions.

Another aspect of the present invention is to provide a computationally fast method which does not rely on previously used segmentation techniques which are error prone.

#### Brief Description of the Drawings

The foregoing and other aspects and advantages will be better understood from the following detailed description of embodiments of the invention with reference to the drawings, in which:

Fig. 1, shows an example of how the image is divided into a local region of interest (ROI) and its neighborhood in accordance with the present invention;

Fig. 2 shows an example of a flow chart of the sequence of decisions and computations made in halftoning in accordance with the present invention;

Fig. 3 gives a detailed description of a priority driven dither computation box in accordance with the present invention.

#### Description of the Invention

Halftone algorithms are either point operations (such as dither) or sequential operations (such as error diffusion). The current invention provides a block-dither method, which involves a limited dependence on the local surround of a pixel. An example embodiment of the present invention examines a digitized document, and decides for each local area (say a 3x3 window or even 1x2) how much gray the printer needs to put down. This determines the number of pixels to be turned on, based on a calibration table. Then a decision is made as to how these pixels are distributed spatially.

Consider a case in which M pixels are to be printed. In this case M pixels are to be turned "on" with ink. A stack is constructed which is initialized to the position sequence of the gray values in a given 3x3 dither matrix. This stack serves to prioritize the different pixels that could be printed in the 3x3 window. The gray values in the 3x3 window are conditionally sorted, as explained below, and the M black

1 values are assigned to the resulting lowest M gray levels. In  
2 this way, a uniform gray level area is printed as a  
3 pre-determined halftone pattern. The input data dictates the  
4 number of pixels to be turned "on". In an embodiment, the  
5 positions of the lowest gray values (darkest pixels) in the  
6 input image are allowed to override the default sort order in  
7 the stack. This achieves a smooth transition between halftones  
8 and text. This results in better localization of features, in  
9 that the printed pixel matches the features in the input image  
10 that deserve the most ink. When a pixel in the image calls for  
11 a pixel of ink, the method generates this ink pixel at the  
12 correct location. This is advantageous to other halftoning  
13 schemes such as error diffusion which cannot provide this  
14 feature localization. A used herein a pixel value is the value  
15 of that pixel's intensity or brightness.

16 Figure 1, shows an example embodiment of how an image is  
17 divided into a local region of interest (ROI) and its  
18 neighborhood. The computations for a given pixel are based on  
19 the ROI and its neighborhood. In Figure 1 a region of interest  
20 ROI, 102, is chosen from the input image, 101. The region in  
21 this case is shown to be a 3x3 window. Other window sizes up  
22 to or more than 128x128 are used in accordance with the  
23 particular application and/or number of pixels in a text  
24 character and/or image part. In general the window can have  
25 any shape. It is advantageous to choose a regular shape such  
26 as a rectangle or a circle to keep the size of the window  
27 sufficiently small in order to capture local variations rather  
28 than global variations. The neighborhood of the ROI, 103,  
29 includes the additional image pixels from which we obtain  
30 statistics. The image pixel values within the ROI are

1 transformed to binary values and placed in corresponding  
2 positions in the output image according to the method described  
3 in Figures 2 and 3. The entire image is covered by tiling the  
4 ROIs so that adjacent ROIs don't overlap. For instance, in  
5 Figure 1, ROI 102 is shifted by 3 pixels to the right for the  
6 next iteration. Since the computations for each ROI are  
7 independent of the computations for any other ROIs, these  
8 operations can be carried out in parallel or in any sequence.

9 In the following discussion, a high dynamic range is said to  
10 occur when the difference between the highest and lowest  
11 intensity values is high, such from 150 to 240 (out of a 0 to  
12 255 range for 8 bit pixel values). A medium dynamic range is  
13 said to occur when the difference between the highest and  
14 lowest intensity values is medium, such as from 50 to 149. A  
15 low dynamic range is said to occur when the difference between  
16 the highest and lowest intensity values is low, such as from 15  
17 to 49. Values outside these ranges are either very low or very  
18 high.

19 Example embodiments are given for four cases. These cases  
20 consider different dynamic ranges of image intensity values in  
21 the ROI and it's neighborhood. Those familiar with the art  
22 will realize that the concepts of the present invention are  
23 applicable to other cases and combinations.

24 A first case occurs when the image intensity values vary  
25 over a high dynamic range. This typically occurs in text  
26 areas which show large transitions between black and white  
27 regions. Hence, a large difference between the minimum  
28 and maximum values in the ROI and it's neighborhood is  
29 useful to indicate the presence of text areas or very



1 coarse halftones. In these regions it is advantageous to  
2 use a first halftoning rule to compute a dynamic threshold  
3 and apply it to the ROI. This thresholding operation  
4 generally renders text areas in a pleasing manner. It is  
5 superior to straight forward halftoning of these text  
6 areas which would cause these text areas to appear  
7 blurred.

8 A second case to consider is when the image intensity  
9 values vary over a low dynamic range. This is typical for  
10 continuous tone gray areas which contain slowly varying  
11 image intensities. In this situation, it is advantageous  
12 to use a second halftoning rule for the rendering method,  
13 which is to apply halftoning using a dither matrix. This  
14 permits the gradual shift of the application of this  
15 method to medium dynamic range areas.

16 A third case occurs when the image intensity values vary  
17 over a medium dynamic range. If the dynamic range is not  
18 clearly high or low, either of the above rendering methods  
19 is not perfect. In this case a third halftoning rule is  
20 employed to use a mixed procedure. In the third  
21 halftoning rule the halftone procedure is modified by  
22 first placing the printed pels in the darkest areas of the  
23 ROI. The remaining printed pels are placed according to  
24 the dither matrix. In general, a convention is used such  
25 that a printed pel of "1" represents ink, corresponding to  
26 dark areas. A printed pel of "0" represents no ink,  
27 corresponding to light areas.

A fourth case occurs when all the image intensity values are either very high or very low. In this case a fourth halftoning rule is used such that all "0"s are printed at the very high intensity values or all "1"s are printed at very low intensity values.

Application of the halftoning rules is dependent upon the particular case determined by examination of the intensity values of each ROI and its particular neighborhood. The computation carried out for each position of the ROI is described with references to Figures 2 and 3. A next (or first) ROI is chosen 201. We first compute the minimum, (min) and maximum, (max.) pixel values in the ROI and it's neighborhood 202. A determination is made as to whether the fourth halftoning rule applies 203. If the minimum pixel value is very high (as defined by the user for example) or if the maximum pixel value is very low, then we apply the fourth halftoning rule 204 and proceed to the next ROI.

If the fourth rule does not apply, we compute the difference delta between the max and min values 205. We determine if delta is less than a predetermined value, HalftoneLimit206. If no, compute the threshold of the pixels 'T' within the ROI 207.

The threshold, T, is the average of the min and max values.

If the graylevel of a pixel within ROI is greater than T we print a "0". Otherwise we print a "1" 208 and obtain a next ROI 201. The HalftoneLimit is defined as the lower limit of the high dynamic range, i.e. 150 for the examples given above.

If delta is less than the HalftoneLimit we use a priority driven dither method 209 and obtain a next ROI if any 201.

1 Figure 3 shows an example of a priority driven dither method.  
2 The first step in the dither method is to determine the number  
3 of pels, N, to print in the ROI 302 for the given ROI 301.  
4 This may be done in any number of ways. One example embodiment  
5 takes the average gray value within the ROI and uses a lookup  
6 table to obtain N from this average. A parallel step is to set  
7 a predetermined order for printing pels in this ROI based on  
8 some given dither matrix 303. It is assumed that we have a  
9 large dither matrix of a size greater than the ROI. The  
10 location of the ROI within the original image determines the  
11 subset of the dither matrix which is used. This is performed  
12 using the standard tiling operation performed in conventional  
13 halftoning known to those familiar with the art. The next step  
14 is to conditionally sort the pixels in the ROI based on their  
15 pixel values 304. Conditional sorting is explained below.

16 Figure 4 shows an example of an initial sequence for printing  
17 pels within an ROI 400 based on some dither matrix. Assuming a  
18 uniform gray area, "1" represents the first pixel to be printed  
19 401, "2" represents the second pixel 402, and so on until "9"  
20 represents the last pixel 409 of the 3x3 ROI to be printed. In  
21 accordance with the present invention, this initial sequence is  
22 modified depending on the data present within the ROI. Assume  
23 the ROI has an image 500 as shown in Figure 5. The image 500  
24 shows a dark pixel in the lower right corner 501. The initial  
25 sequence 400 is processed through a sorting technique to  
26 produce a final sequence 600 shown in Figure 6. Note that the  
27 dark pixel 601 in the lower right corner is now printed first  
28 and subsequent entries maintain their otherwise relative  
29 sequence order.

1 A sorting technique in accordance with the present invention is  
2 described as follows. In all sorting we start with some  
3 initial ordering of the items to be sorted. In a conventional  
4 sorting technique, such as in a bubble sort, two adjacent items  
5 are swapped if one is greater than the other. In the present  
6 technique the same two adjacent items are swapped only if one  
7 is greater than the other by a prespecified amount,  $n$ , as shown  
8 in 304. When items are not swapped, the original relative  
9 order is maintained. In this way, only significant differences  
10 in item values result in reordering of the original sequence.

11  
12 In situations where the ordering of the image intensity values  
13 differ significantly from the ordering of the dither matrix, a  
14 complete reordering generally occurs. In these cases pels are  
15 printed only where the pixels are darkest. This is equivalent  
16 to a threshold operation and is such as to provide a smooth  
17 transition between a first case, high dynamic range, and a  
18 third case, medium dynamic range. This operation directs ink  
19 to those pixels that are the darkest such that it closely  
20 follows details in the image.

21 In situations where most of pixel values are the same with only  
22 a few exceptions, the initial printing sequence will be changed  
23 only slightly. This provides a smooth transition between a  
24 third case, medium dynamic range, and a second case, low  
25 dynamic range.

26 It is noted that the current invention differs from the method  
27 of Goertzel and Thompson (US Patent 4,654,721) in a number of  
28 ways. In Goertzel and Thompson, the image goes through a  
29 scaling operation, such that 9 pels are printed for each input

1 pixel. Therefore the pattern of the 9 pel area is determined  
2 by the ordering of pixels in a larger 9 pixel area.  
3 Furthermore, this was only done when a gradient criterion was  
4 exceeded. In contradistinction the present invention does not  
5 use the pattern derived from a larger area to determine the  
6 pels printed in a smaller area. Also, in the present  
7 invention, the ordering scheme is very different in that a  
8 pre-assigned (priority) order is chosen. The order is changed  
9 only if the difference in pixel values exceeds some threshold  
10 value. The Goertzel-Thompson invention was generally based on  
11 lower resolution input data and is thus not capable of  
12 reproducing the level of image detail reproduced with the  
13 method of the present invention.

14 It is noted that the present invention can be realized in  
15 hardware, software, or a combination of hardware and software.  
16 The present invention can be realized in a centralized fashion  
17 in one computer system, or in a distributed fashion where  
18 different elements are spread across several interconnected  
19 computer systems. Any kind of computer system - or other  
20 apparatus adapted for carrying out the methods described herein  
21 - is suitable. A typical combination of hardware and software  
22 could be a general purpose computer system with a computer  
23 program that, when being loaded and executed, controls the  
24 computer system such that it carries out the methods described  
25 herein. The present invention can also be embedded in a  
26 computer program product, which comprises all the features  
27 enabling the implementation of the methods described herein,  
28 and which - when loaded in a computer system - is able to carry  
29 out these methods.

1 Computer program means or computer program in the present  
2 context mean any expression, in any language, code or notation,  
3 of a set of instructions intended to cause a system having an  
4 information processing capability to perform a particular  
5 function either directly or after conversion to another  
6 language, code or notation and/or reproduction in a different  
7 material form.

8 It is noted that the foregoing has outlined some of the more  
9 pertinent objects and embodiments of the present invention.  
10 This invention may be used for many applications. Thus,  
11 although the description is made for particular arrangements  
12 and methods, the intent and concept of the invention is  
13 suitable and applicable to other arrangements and applications.

14 It will be clear to those skilled in the art that  
15 modifications to the disclosed embodiments can be effected  
16 without departing from the spirit and scope of the invention.  
17 The described embodiments ought to be construed to be merely  
18 illustrative of some of the more prominent features and  
19 applications of the invention. Other beneficial results can be  
20 realized by applying the disclosed invention in a different  
21 manner or modifying the invention in ways known to those  
22 familiar with the art.

1     CLAIMS

2     Having thus described our invention, what we claim as new and  
3     desire to secure by Letters Patent is as follows:

4     1. A method for transforming a digitized image, said method  
5     comprising:

6     providing said image as a plurality of pixels, wherein data for  
7     each pixel is in a first format; and

8     halftoning said data of each of said pixels by employing data  
9     from a region of interest which includes at least one pixel  
10    following said each-of-said pixels, and producing a second  
11    format for said image.

12    2. A method as recited in claim 1, wherein the region of  
13    interest includes a plurality of neighboring pixels.

14    3. A method as recited in claim 2, wherein the neighboring  
15    pixels form a symmetrical pixel array surrounding said each of  
16    said pixels.

17    4. A method as recited in claim 3, wherein the symmetrical  
18    pixel array forms a square.

19    5. A method as recited in claim 1, further comprising using  
20    said second format for an output device.

1 6. A method as recited in claim 5, wherein said output device  
2 is a printer.

3 7. A method as recited in claim 1, further comprising  
4 determining a dynamic range of pixel values of pixels in an  
5 encompassing neighborhood of the region of interest, and  
6 wherein the step of halftoning includes making dynamic  
7 adjustments depending on the dynamic range of pixel values.

8 8. A method as recited in claim 7, wherein the step of making  
9 dynamic adjustments includes producing a visually pleasing  
10 transition between text and picture areas in said image.

11 9. A method as recited in claim 8, wherein the step of  
12 producing a visually pleasing transition includes:

13 if said dynamic range is high,  
14 computing a pixel data threshold value for said region of  
15 interest;

16 comparing each pixel value in said region of interest to  
17 said pixel data threshold;

18 if said pixel value is greater than the pixel data  
19 threshold value, a first value is placed in the corresponding  
20 position of the said second format image;

21 if said pixel value is less than or equal to the pixel  
22 data threshold value, a second value is placed in the  
23 corresponding position of the said second format image;

24 if said dynamic range is medium,  
25 computing a desired number of second values to be placed in  
26 said second format image in the region of interest;



1 ordering the pixels in the region of interest according to  
2 the ordering of a predetermined halftone array;

3 altering the order of a pixel in said ordering if said  
4 pixel has a value which is greater than the value of the next  
5 pixel in said order by a predetermined reordering threshold  
6 value;

7 repeating said altering of the pixel order until the first  
8 and second values chosen for the second format image are no  
9 longer changed;

10 choosing said desired number of second values for the  
11 second format from the beginning of the said order, and  
12 assigning the remaining pixels values in the region of interest  
13 to said first value;

14 if said dynamic range is low,

15 using said predetermined halftone array to compute said  
16 first and second values for said second format image;

17 if all the image intensity values in the said ROI are either  
18 very high or very low, outputting all said first values or all  
19 said second values to the second format image respectively.

20 10. A method as in claim 9, where we determine a number of  
21 second value to be placed in said second format image based on  
22 a weighted function of the image intensity values within the  
23 region of interest of the first format image

24 11. A method as in 9, wherein the plurality of  
25 regions-of-interest form the entire said first format image.

1 12. An article of manufacture comprising a computer usable  
2 medium having computer readable program code means embodied  
3 therein for causing a digital image to be transformed, the  
4 computer readable program code means in said article of  
5 manufacture comprising computer readable program code means for  
6 causing a computer to effect the steps of claim 1.

7 13. A program storage device readable by machine, tangibly  
8 embodying a program of instructions executable by the machine  
9 to perform method steps for transforming a digitized image,  
10 said method steps comprising the steps of claim 1.

11 14. A method for halftoning at least a portion of an image,  
12 the method comprising employing a first rule of halftoning and  
13 a second rule of halftoning.

14 15. A method as recited in claim 14, further comprising  
15 employing a third rule of halftoning and a fourth rule of  
16 halftoning.

17 16. An article of manufacture comprising a computer usable  
18 medium having computer readable program code means embodied  
19 therein for causing halftoning at least a portion of an image,  
20 the computer readable program code means in said article of  
21 manufacture comprising computer readable program code means for  
22 causing a computer to effect the steps of claim 14.

23 17. An article of manufacture comprising a computer usable  
24 medium having computer readable program code means embodied  
25 therein for causing halftoning at least a portion of an image,  
26 the computer readable program code means in said article of

1 manufacture comprising computer readable program code means for  
2 causing a computer to effect the steps of claim 15.

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## 1                   PRIORITY-DRIVEN DITHER.

## 2                   ABSTRACT

3       The present invention presents halftoning techniques for  
4       printers and solves problems related to halftoning so as to  
5       render a combination of text and image areas in a pleasing  
6       manner. An advantage of this technique is that it gradually  
7       switches from text rendering to picture rendering in a manner  
8       which is locally adaptive over small regions, (say 3x3 pixels).

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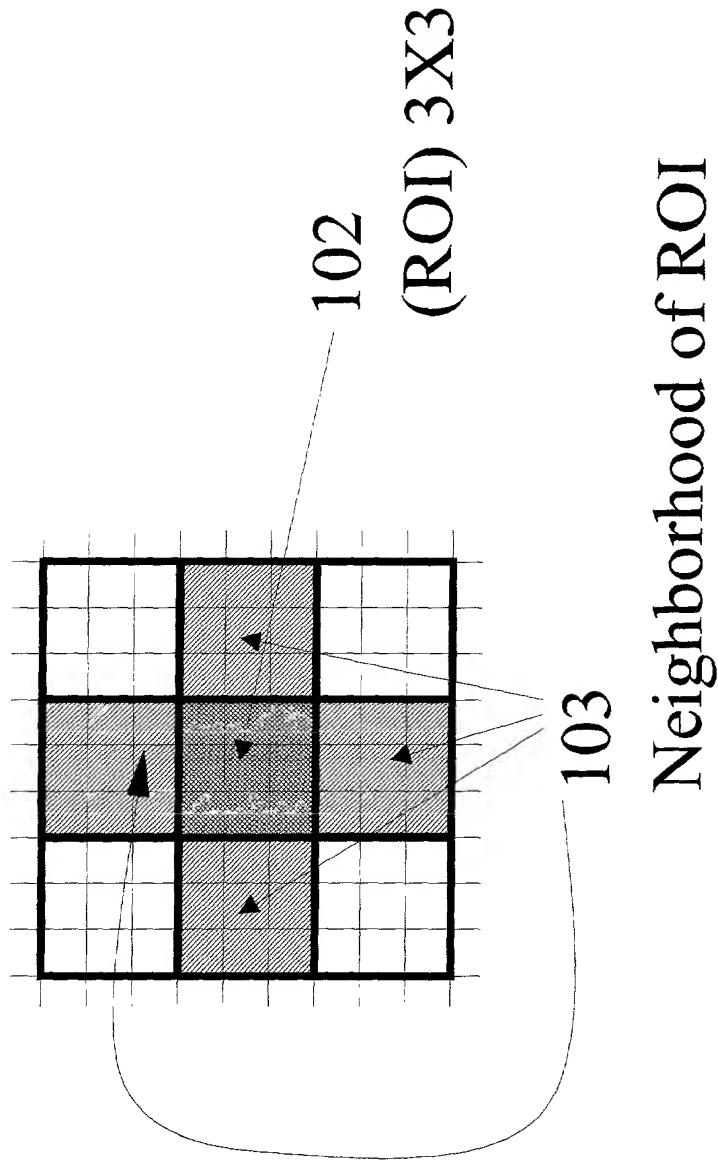


Fig. 1

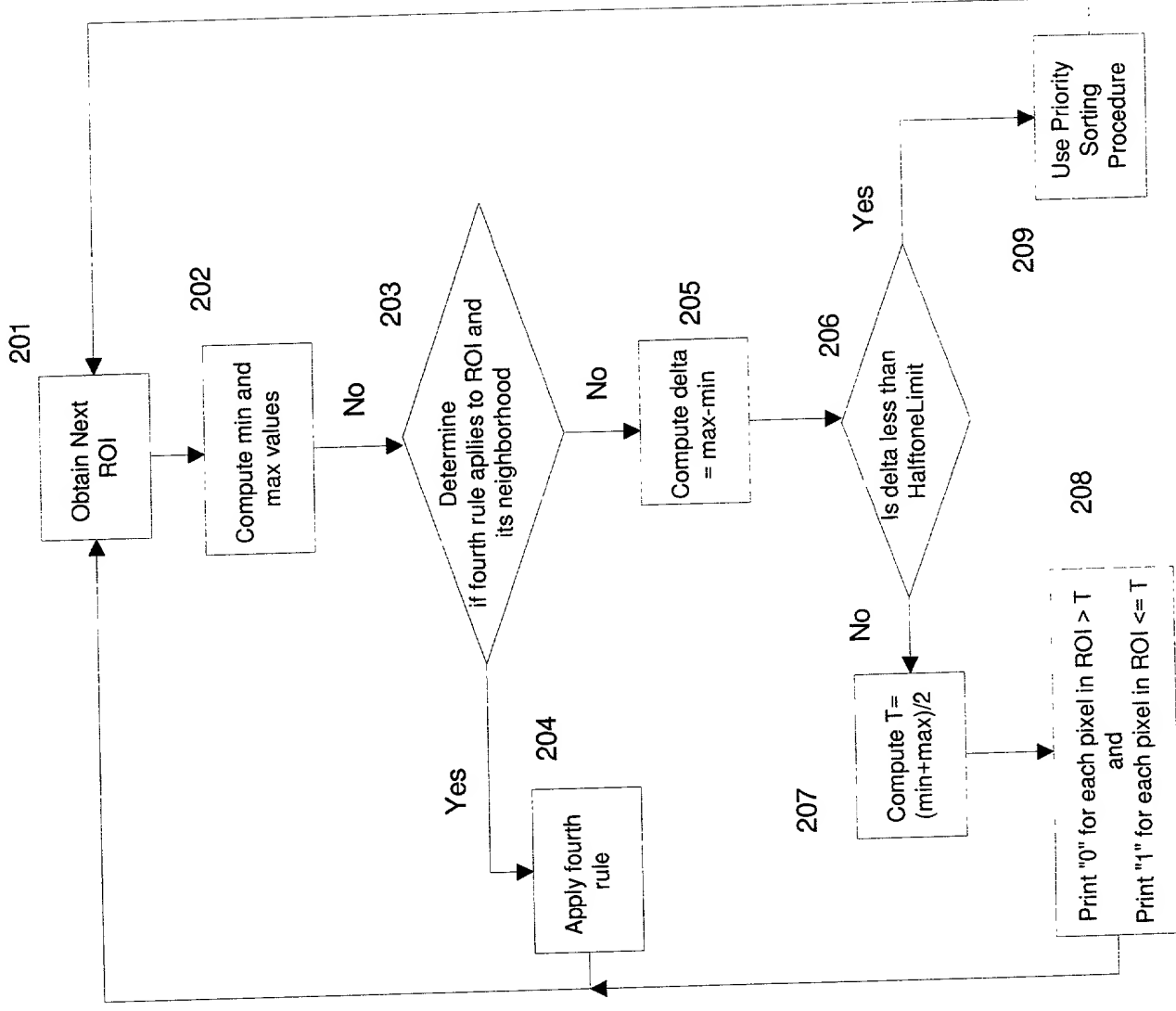


Fig. 2

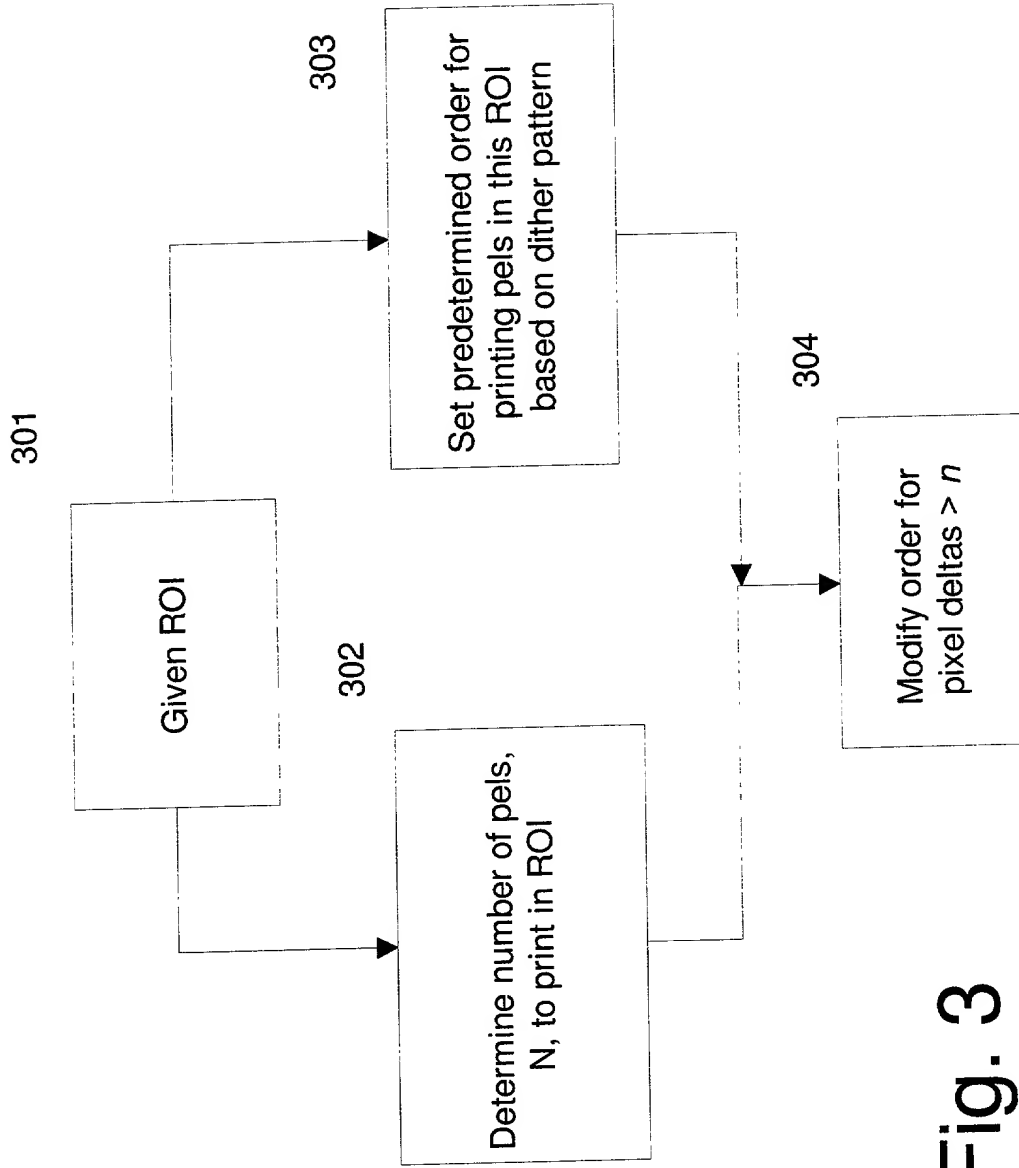


Fig. 3

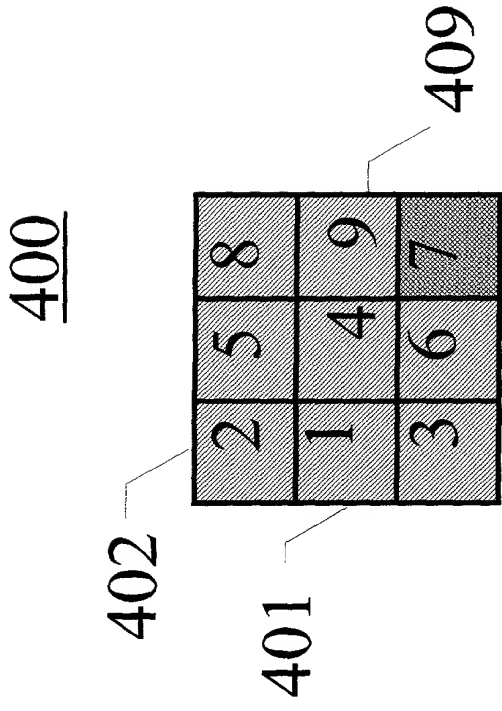


FIG. 4



500

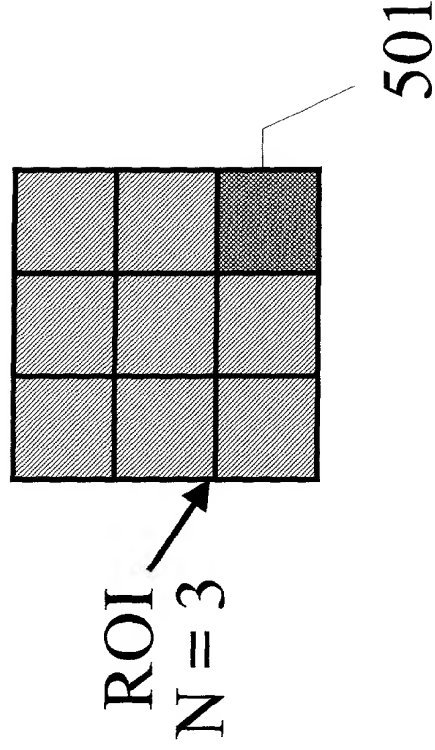
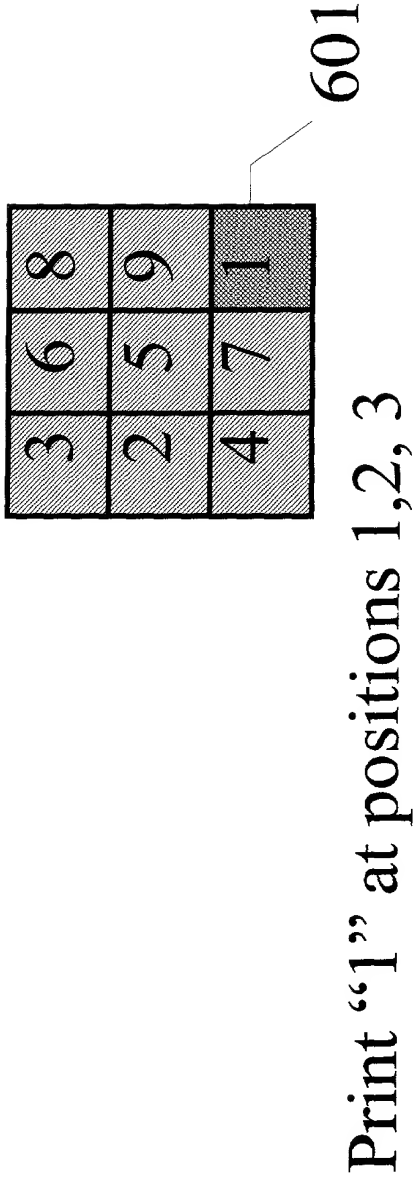


FIG. 5

600



Print “1” at positions 1,2, 3  
“0” elsewhere

FIG. 6

**DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

PRIORITY-DRIVEN DITHER

the specification of which (check one)

X is attached hereto.

\_\_\_\_\_ was filed on \_\_\_\_\_ as United States Application Number \_\_\_\_\_

or PCT International Application Number \_\_\_\_\_

and was amended on \_\_\_\_\_ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, '119(a)-(d) or '365(b) of any foreign application(s) for patent or inventor's certificate, or '365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application, having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed	
(Number)	(Country)	(Day/Month/Year Filed)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
(Number)	(Country)	(Day/Month/Year Filed)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
(Number)	(Country)	(Day/Month/Year Filed)	<input type="checkbox"/> Yes	<input type="checkbox"/> No

I hereby claim the benefit under 35 U.S.C. '119(e) of any United States provisional application(s) listed below.

(Application Number)	(Filing Date)
(Application Number)	(Filing Date)

I hereby claim the benefit under 35 U.S.C. '120 of any United States Application(s), or '365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States, or PCT International application in the manner provided by the first paragraph of 35 U.S.C. '112, I acknowledge the duty to disclose information material to the patentability of this application as defined in 37 CFR '1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that willful false statements may jeopardize the validity of the application or any patent issued thereon.

**POWER OF ATTORNEY:** As a named inventor I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith (list name and registration number).

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